A Civil Infrastructure System Perspective - Not Just the Built Environment

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1 Introduction

Based on a perceived need within the Department of Civil and Environmental Engineering at the University of Utah to increase faculty and student awareness of 1) the national infrastructure crisis and 2) a departmental-wide pedagogical approach to engineering instruction with a more holistic, global understanding of infrastructure systems, three faculty members attended the 2nd Annual Infrastructure Education Workshop on *Pedagogies of Engagement in Infrastructure Classrooms*. Hosted by the Center for Infrastructure Transformation and Education (CIT-E), over 30 national faculty members participated in a three-day, best-practices teaching seminar and workshop held on the campus of the University of Utah in Salt Lake City, Utah (May 2015). One of the primary goals of this and subsequent workshops is to grow a community of practice focused on creating learning modules to populate an open-source teaching and research database on infrastructure education.

This paper discusses our use of the workshop materials including modifications made to them to fit our local environment. The paper describes additional activities inspired by and/or designed to complement the workshop materials. Crucial questions for our project team included: What does infrastructure education mean and how does it differ from civil engineering education? How do we teach it? And, how do we assess student achievement within it? The work reported here is, in essence, a pilot study of initial efforts to answer these questions. In this process, we both broadened and deepened our understanding of what the infrastructure perspective means and how it informs the delivery and assessment of a baccalaureate program. Part of our assessment of this pilot study includes descriptions and analyses of student deliverables by both direct and indirect methods.

2 Background – Defining both the What and the Need

A variety of nationally-based organizations have called for a focus on infrastructure renewal and research.[1,2,3,4] These include the National Science Foundation (NSF), the US Green Building Council (USGBC), American Society of Civil Engineers (ASCE), and The Institute for Sustainable Infrastructure (ISI). Although it may seem obvious what civil infrastructure is, the definition of infrastructure varies depending on the mission and vision of the organization. The USGBC and its LEED™ certification program is focused on building systems and therefore encourages users to consider how different systems within the building and its construction can be treated holistically from an energy and sustainability perspective. The ISI and the Envision™ process focuses more broadly on large-scale systems such as roadways, pipelines (sewers), and related systems. The two, as a whole, encompass much of the broad range of the application of civil engineering, but neither is comprehensive by itself in defining civil infrastructure. Both, though, reference the built-environment (also called "grey" infrastructure) and may also include physical, chemical, or biological processes as well as the impact on energy and sustainability. And, while both support innovation; neither explicitly includes the involvement all stakeholders in the project, where stakeholders are defined broadly as anyone who might have an interest or be impacted by a given project.

The Civil Infrastructure Systems (CIS) directorate at the National Science Foundation provides a working definition in its call for research into "designing, constructing, managing, maintaining, operating and protecting efficient, resilient and sustainable civil infrastructure systems."[1] Furthering this aim, CIS encourages research that "recognizes the role that these systems play in societal functioning and accounts for how human behavior and social organizations contribute to and affect the performance of these systems."[1] In other words, civil engineers must be able to work with a variety of partners and stakeholders in a holistic fashion. Civil engineers must be aware of multiple needs and socio-economic, political, and environmental factors that impact civil engineering systems while remaining cognizant of the impacts that those systems have on society.

2.1 National Infrastructure Crisis

No longer does it appear sufficient for civil engineering practitioners to meet bare minimum technical skills sets required for a particular positon. Rather, as has been expressed variously by ASCE over the past 15 years, it is increasingly necessary that civil engineers also develop professional skill sets that includes an ability to communicate, lead, and function with multiple partners in projects that directly support sustainable practices (design, construction, operation, etc.).[5] CIT-E is an NSF-supported response from the civil engineering education community to begin to understand the "changing landscape" of both practice and education.[6] The primary goal of CIT-E is to develop a community of practice of educators passionate about and dedicated to helping define what this new landscape is and to develop and share tools by which the entire educational community can meet these emerging educational directives.

2.2 Global Learning Outcomes

A second (but not secondary) need includes a call for increased global cultural awareness on the part of civil engineering graduates and practitioners.[5,7,8,9, 10, 11, 12, 13] The Association of American Colleges and Universities (AAC&U) "has identified global knowledge, ethical commitments to individual and social responsibility, and intercultural skills as major components of a 21st century liberal education."[9] These global learning initiatives are becoming more widespread and implemented across U.S. higher education institutions.[10] In some views, these initiatives are no longer a subject for debate but are critical to the mission of most institutions.[9] Although developed from a slightly different perspective and focus, ASCE's *Body of Knowledge for the 21st Century*[5] (BOK) grew from a similar understanding that successful engineers must contribute more broadly to the global community than simply acting as a technical calculator (expert); they must also engage and collaborate with multiple partners in their work.

A detailed examination of global learning outcomes at the University of Utah and their connection to infrastructure education is provided in a companion paper.[12] A primary basis of that work is a recognition that the term global has multiple aspects. While international diversity encompasses the commonly understood aspects of ethnic and geographical diversity, it is use to describe cultural diversity and the various sub-cultures associated with different disciplines. For example, the typical civil engineering consulting office includes business staff, engineering staff, technician staff, administrative staff, etc. Each of these has its own customs, organized ways of thinking, and group identifications and often times can be as varied as verbal languages, e.g., English, French, etc. while displaying similar challenges in cross-cultural situations.

The cultural intelligence community embraces this viewpoint and ultimately shares much in common with the global learning community and the infrastructure education community. Each seeks to engage as many different needs and viewpoints as feasible.

2.3 The Existing Curriculum

In the early 2000's, the Department of Civil & Environmental Engineering at the University of Utah refocused their undergraduate program to more integrally support professional skill set related outcomes. Driven perhaps more directly by local stakeholders, the new direction inherently aligned with the national vision expressed by ASCE.[14, 15] Outcomes included areas in communication, public policy, business, public administration, globalization, leadership, teamwork, professional ethics and responsibility, and the context of professional practice and design.

Three required courses were designated as the vehicle for delivering and assessing learning experiences in the professional skill sets area. The sequence was designed to begin development of professional skills in the first semester (CVEEN 1000 Introduction to Civil Engineering), broaden and deepen them in the fifth or sixth semester (CVEEN 3100 Technical Communications for Civil Engineers), and culminate their development in the eighth semester (CVEEN 4910 Professional Practice & Design, the capstone design experience for the program).

3 Response to the Need

Our initial enthusiastic response to the CIT-E summer workshop was tempered once we considered that the timing for large-scale change was not ideal. The program had just completed an ABET accreditation self-study and was preparing for a campus visit at the beginning of the next term (Fall 2015). Simultaneously, we had begun an audit of our program in regards to global learning outcomes. Given the potential overlap and strong connection to the professional skills core, we focused on small-scale interventions and chose to approach changes cautiously by conducting a small pilot study involving the courses in the professional "core."

Three course were selected (CVEEN 1000, 3100, and 4910) as appropriate candidates. These courses represent students from across the program and constitute the core of the department's professional skills-related offerings. Practical issues caused the co-authors to implement the infrastructure theme in only two courses: CVEEN 1000 and 3100. The capstone course (CVEEN 4910) was already overloaded with a focus on development and execution of design projects; as well, many aspects of an infrastructure perspective were already embedded in the course from the outset of this study.

4 Rubric Development

The initial focus in the two courses was in how to implement selected ideas from the CIT-E Infrastructure Education Workshop. The workshop itself focused more on the development of lessons and/or modules and not as much on detailed assessment rubrics. As the co-authors focused on implementing the lessons and developing a rubric for assessment, we were also led to a more clear understanding of infrastructure education. This understanding has become our primary outcome of this paper.

A variety of initiatives to develop global learning related outcomes and rubrics have been developed across the United States such as the AAC&U Valid Assessment of Learning in Undergraduate Education (VALUE) initiative.[13] The VALUE rubrics include a comprehensive set of critical thinking competencies: Inquiry and Analysis, Critical Thinking, Creative Thinking, Written Communication, Oral Communication, Quantitative Literacy, Information Literacy, Reading, Teamwork, Problem Solving, Civic Knowledge and Engagement – Local and Global, Intercultural Knowledge and Competence, Ethical Reasoning and Action, Global Learning, Foundations and Skills for Lifelong Learning, and Integrative Learning. The VALUE rubrics have been approved for use in meeting national standards for accountability established by the Voluntary System of Accountability.[13]

The Infrastructure Rubric presented here is blended from the VALUE rubric, the ASCE BOK, CIT-E's model of infrastructure engineering, and a representation of the civil engineering design process. The rubric has three areas: Project Need, Project Challenges, and Project Success. Each of the three components is amplified by a variety of components as shown in Table 1. Identification of Stakeholder, needs, desires, and conflicts is taken together in the Project Need area. The Project Challenge area encompasses much of the traditional focus of an undergraduate engineering program: engineering-related models and calculations. Note a crucial broadening of this area with a focus on hazard identification, modeling, and interdependencies. The Project Success area as well focuses on explicitly enabling (and requiring) that a project be assessed in a multitude of areas beyond technical: safety, health, welfare, sustainability, resilience, and impact.

Table 1 should not be considered as a sequential flow chart for project execution although it does share some elements of a procedure. In the infrastructure perspective, it is recognized that all areas interact with each other and, as such, are developed together.

Table 1: Infrastructure Rubric Areas.

Project Need	**Project Challenges**	**Project Success**
Stakeholders - Interests - Needs - Competing Interests	Hazards - Natural - Manmade - Economic - Social - Political - Consequences - Interdependence Engineering Challenges - Technical Models - Technical Form and Function - Construction Means and Methods	Success Areas - Engineering - Safety - Health - Welfare - Sustainability - Resilience - Impact

Bloom's Taxonomy of Cognitive Skills[16] was selected as a basis from which to establish performance levels in each of the sub-areas of the rubric. Due recognition was given to the discussion regarding Evaluation and Synthesis levels and which represents a higher level of performance.[17, 18, 19, 20, 21] For our purposes, we were satisfied if students performed at any of the top three highest levels and were not as concerned about didactic issues of which of the top two levels should be regarded as higher.

The rubric components represent an attempt to evaluate student progress not just within individual courses but more broadly across all four levels of the program and thereby establish a baseline of student-learning outcomes for the department. In the spirit of a pilot study, it must be noted that the rubric was used more as a tool to conjoin our mutual understanding of what we were attempting to accomplish more than it was a direct measure of student achievement. The detailed rubric is shown in the Appendix of this paper.

5 Teaching Interventions in CVEEN 1000 Introduction to Civil & Environmental Engineering

5.1 Background of Course

In this first semester, 2-credit hour (30 lessons), required introductory course in civil engineering, students develop a basic understanding of how society functions, how societal needs can be incorporated into the design of a project, and how society impacts the functioning of engineering practice. Integral are topics focused on the broader aspects of leadership, ethics, professional responsibilities, and contemporary issues ranging from business practices to sustainability. The content of the course is delivered via active exercises facilitated by guest speakers (faculty and industry representatives) and peer-instruction (via student presentations of their team projects).

The course meets twice a week with each meeting comprised of 80-minutes of contact time. The weekly contact time is divided between a variety of structured learning ("lecture") and project ("lab") activities. The daily balance of "lecture" and "lab" time varies; the goal is an even split. Student enrollment ranges from 50 to 95. The course attracts a large number of students who may not necessarily be serious about civil engineering as an academic pursuit. It is common to see a 50% turnover from the first to third semester although total enrollment is about the same. Roughly, 50 percent of the students are residents of the state. Gender diversity (in traditional terms) is roughly a 1:2 ratio (female to male). Students who are not in their first semester of higher education range from 30 to 50 percent. About 15 to 20 percent are international students. Student motivations range somewhat equally from a predisposition to "saving the world through engineering and technology" to "good salary opportunities" to a committed interest in the technical details and applications of the career.

5.2 Learning Activities – Infrastructure Design of the Course

The course used to use two historic texts written in narrative style [23, 24] to provide a comprehensive introduction to civil engineering. These were replaced with a study of contemporary, infrastructure-focused projects. The course was re-designed to contain two "halves." The first "half" of 20 instructor-guided lessons focuses on the "what" of civil infrastructure engineering and sets up the second, peer-to-peer "half." As those 20 lessons move along, the team portion of the contact time increases. The formal part of the second "half" contains 10 lessons wherein the teams present their project work; the second "half" culminates in a final individual accountability essay, i.e., a final exam.

5.2.1 Bridge Planning – A CIT-E Lesson
From the CIT-E database, the introductory planning lesson for bridge infrastructure was used as the basis of Lesson 2 of the course. The learning outcomes of the lesson included:

- Define the primary factors included in the planning process for a bridge.
- Classify and organize the factors in a generalized model.
- Discuss the effects of poor planning.

Students role-played as representatives of various stakeholders. These included:

Mayor's Office/Town Council	City Business Development Office
State Government	State Department of Transportation
Local business owners	Home owners
Structural engineers	River engineers
Environmental consultants	Construction companies
Transportation engineers	Bridge architects
Historic Preservation	City Engineer's Office

In preparation for the lesson, students were assigned a role and conducted online research into what might be of interest to their assigned stakeholder. During class, they were provided five minutes to discuss their findings with their group (each member of which was assigned the same role) and to prepare a "single answer" to present to the class at large. After a brief round-table discussion, students were provided "official answers" that guided a follow-up activity—to discuss a scenario wherein a "local" bridge had collapsed and what might constitute a stakeholder response. The specific example discussed was that of the I-35 Mississippi River Bridge collapse. The in-class activity was conducted substantially as presented in CIT-E.

A subsequent out-of-class activity prompted students to conduct a web-related research on a (self-selected) bridge "failure." They identified what experts had determined was the cause of the failure and where that causality might fit in the bridge planning model that was provided to them in class. As a result, the vast majority of the students achieved the expected goals: an increased awareness of the infrastructure crises, identification of a specific example of that crises, identification of what might have been done differently in the planning process to have prevented or mitigated the situation. Again, only minor logistical modifications were made from the CIT-E materials.

5.2.2 Infrastructure-Themed Group Projects
The learning outcomes of the project included that the students would be able to: (a) describe civil engineering practice and a typical project, (b) define the typical engineering project structure, (c) discuss how societal needs are incorporated into a project, (d) describe the need for and how innovation manifests itself, and (e) describe what makes a civil engineering project successful (or not). Note the overlap with holistic definition of the civil infrastructure perspective provided by NSF CIS, the inherent connection to ASCE's BOK. The student groups of 3 to 6 students

Table 2 Fall 2015 Infrastructure-Themed Projects

1	NYC Green Infrastructure	**6**	Florida Everglades Restoration
2	Sydney Harbour Bridge	**7**	Elwha River Restoration
3	I-70 Reconstruction through Glenwood Canyon, CO	**8**	English Channel Tunnel
4	Milau Viaduct	**9**	Three Gorges Dam
5	Burj Khalifa	**10**	Netherlands Delta Works

presented their work in both oral and written fashion. All students observed the oral presentations and thereby learned from a suite of significant projects.

Table 2 provides the project list for Fall 2015. Not all projects were contemporary, but most were completed within the past 20 years or are ongoing projects. Four overtly contained sustainability-related themes. All were specifically chosen to enable discussion of large-scale impacts.

The framework and expectations for the group research were primarily communicated via a project template and included the items shown in Table 3. Teams were expected to identify how their specific project was different from the template and make appropriation modifications; one of the early assignments in the project was to perform this analysis. The details of the project template specifically flowed from the CIT-E inspired definition of Civil Infrastructure Engineering.

Table 3: Infrastructure-themed Project Template used for Fall 2015.

Project Area	Components
Project Description	• Location, Type of Facility, Size, Scope, etc. • Connection to Civil Infrastructure (function and role in larger system) • Design and/or Construction Timeline • Design and Development Cost
Project Background and Need	• Stakeholders, Function, Societal Need, Culture Significance
Basis of Success	• Identify each stakeholder's success criteria
Engineering Challenges	• Needs or Issues faced in and/or unique to the project
Engineering Solutions	• Alternative engineering solutions considered • Description of Selected Solution • Engineering and Construction Innovations and/or Technologies implemented
Significance and Relevance	• Long-term Impact of Project to Stakeholders • Success of Project (Current Status, Repairs or Renovations, Sustainability)

Table 4: Assessment Data for Infrastructure Rubric Fall 2015 CVEEN 1000.

Number of Teams that Achieved Performance Level (following Bloom's Taxonomy)

Project Category	Understand	Comprehend	Apply	Analyze	Evaluate	Synthesize	Average	Standard Deviation	Coefficient of Variation
Need	3	0	7	0	0	0	2.4	0.97	0.40
Challenges	2	3	4	1	0	0	2.4	0.97	0.40
Success	3	0	1	6	0	0	3	1.41	0.47

5.3 Assessment of CVEEN 1000

Assessment data associated with the Infrastructure interventions were collected by indirect and direct means. For our purposes, direct meant that we measured each student's achievement in an individual manner. Indirect means that we used team performance to gage student achievement. In particular, we used the team project report and an examination-style essay as the indirect and direct methods, respectively.

Table 4 presents the highest level of performance achieved by each team. For instance, in the Project Need category, three teams reached only the Identification level while seven teams reached the Application level. It must be noted that greater than half of the teams reached the Analysis level when considering the success of the project. Such a high level of performance is more indicative of a relatively easy standard by which they were measured. This may be a flaw of the rubric rather than a high performance by the students. Instead, the criteria for performance at the Analysis level might more accurately be defined as demonstrating an understanding of the competing measures of success for the various project criteria and how to obtain, process, and analyze the appropriate data associated with success in each category. If so, the performance of the students would occur, at best, around the Application level. It is more likely that other levels would then be re-scaled to reflect average performance occurring around a mean of 2.5 (between Comprehension and Application). Note the large coefficient of variation of 0.4. Such a large value suggests significant scatter about the mean. (Given the changing perspective of the validity of null hypothesis significance testing procedure (NHSTP)[25, 26], NHSTP is not presented here.)

Assessment of individual students turned out to be more difficult and time consuming than anticipated. We had expected to use the final essay (exam) to assess the student's level of awareness of the infrastructure paradigm.

Individual Final Essay (Exam) in CVEEN 1000

Select a project (not your own) and use it to discuss:

A. How civil infrastructure enables society to function.
B. How societal needs can be incorporated into the design of a project.
C. The public service and responsibility of a civil engineer.
D. How that project was enhanced (or not) by the infrastructure perspective.

Of the various difficulties that arose in evaluating the student work, time to evaluate a larger number of essays was certainly one. More importantly, though, the level of writing provided by the students was such that assessing the quality of the content of their responses became difficult to the point of concern about the validity of the assessment. There was not any problem in determining a score in terms of class purposes. That was relatively simple our desire was for students to demonstrate some level of reflection and integration of the course ideas.

Assessment of the efficacy of the teaching approach for the semester was clearly clouded by the actual substance of the student work. Did they not make the connections that we wanted because of their ability? Or, our ability as teachers? Was the instrument flawed? Did we provide sufficient examples, practice, and feedback that we should hold the students accountable for their writing quality? Are we expecting too much of what are nominally first semester students?

Finally, the instructional team returned to the original premise of both the intervention and that reported in this paper: we are trying to teach ourselves about what the infrastructure paradigm is and are not as concerned at the moment about whether the specific teaching methods are efficacious. We are not attempting to demonstrate a better way to teach; rather, we seek first to define this content and what then to understand what it means in the context of leading others to a new vision first. This effort involves trying a few things with our students and we can use their responses to guide us to a more clear way forward. From that we perspective, we felt the exercise was a success because students clearly understood that important connections exist between society and the practice of civil engineering.

For our next implementation of the course (and the rubric), we anticipate integrating two or three writing assignments during the term. As well, we anticipate refining the rubric, expanding it closer to something resembling the Project Template (Table 3) rather than leaving it in a broader form (Table 1).

5.4 An Accompanying Risk and Decision Analysis Exercise

Incorporation of risk and decision analysis from a business perspective was also introduced by the process of assigning students to a project team. Each student was given a “budget” of $100,000 with which they could bid on a project. They could bid on one project or spread their funds among many; there were 12 initial projects available. If a student desperately wanted a specific project, they could rank it number 1 and allocate all of their money to it. However, if they were unlucky to have chosen a popular project and there were too many others who did the same thing, then that student might not actually win their favorite. If they had planned on only one option, they would then be at the mercy of the instructors for whatever project was left over. Most of the students approached the situation using a tiered approach. They selected three projects and either balanced their money across all three, or put a little more on their top rank and about the same on the other two.

6 Teaching Interventions in CVEEN 3100 Technical Writing

6.1 Background of Course
In this required, 3-credit hour, junior-level civil engineering course, students develop a more robust understanding of how society functions, how societal needs are incorporated into the design of a project, and how society impacts the functioning of engineering practices. It is intended the students develop creative thinking and substantive awareness demonstrated by a change in the manner and substance of their work product. The assessment is facilitated by Bloom's Taxonomy.

Typically, CVEEN 3100 enrolls 20-30 students, all of whom have declared a major with the Department of Civil and Environmental Engineering. As with CVEEN 1000, students in the course tend to represent a wide variety of cultural and academic backgrounds. End of semester student evaluation feedback reveals mixed attitudes toward the required course. While many students appreciate "covering multiple forms of writing, all of which will be used in our careers" and is "good practice for the professional world," some of the students express a general disregard for the class as "unnecessary" as it distracts from more technically-oriented courses in the curriculum. Implicitly, this perspective assumes that a professional program's primary focus should be to train rather than teach a framework by which to think, feel, emote, interact, or communicate.

6.2 Learning Activities – Infrastructure design of course
Learning activities occur via a variety of individual and collaborative activities and projects. For example, activities included memorandum writing, technical presentations, and a formal feasibility report. Students are required to submit proposals to conduct research before delivering a technical presentation on their research findings. For the final report, students are grouped in 3 to 4 member teams. Each team prepares a chapter that is then compiled into a single class report. Each chapter ranges between 20 and 30 pages. At the end of the term, each team also presents their chapter via a 12-minute oral report.

Examples of final course reports include *The Uinta Express Pipeline: A Comprehensive Research Report Conducted by Students Enrolled in CVEEN 3100 Technical Communications* (FA 2014) and *The Blue Castle Project (BCP): A Feasibility Study of the Proposed Nuclear Power Plant in Emery County, Utah* (SP 2015).

6.3 Learning Outcomes – Infrastructure focused activities
The primary shift that occurred as a result of the intervention was to discontinue the use of popular novels[27, 28, 29] to discuss current events and the ethical implications of civil engineering; instead, an explicit focus on infrastructure, community resilience, and risk mitigation was devised and incorporated into the course.

6.4 Learning Activities – After Intervention
In CVEEN 3100 (FA 2015), the instructor devised a three-week unit (9 contact hours) on infrastructure, community resilience, and risk mitigation and strategic communication. Some of the teaching materials used during this unit were developed in cooperation with CIT-E workshop attendees. For example, *Assessing Risk and Resilience in Hazardville* is based on a publication

released by the Federal Emergency Management Agency.[30] The remainder of the unit draws attention to infrastructure initiatives occurring within local and regional communities such as the recent Resilient Cities Summit hosted by the National League of Cities[31] and the “Your Utah, Your Future Vision for 2050” [32] survey conducted by Envision Utah. Students were required to write several memorandums over the course of the unit, which culminated in a short (3 to 5 minute) oral presentation and a formal written report (4 to 5 pages).

Table 4: Assessment for Infrastructure Rubric CVEEN 3100 (FA 2015): Individual achievement of Bloom’s Taxonomy

Project Category	Understand	Comprehend	Apply	Analyze	Evaluate	Synthesize	Average	Standard Deviation	Coefficient of Variation
Need	1	2	4	3	0	0	2.90	0.99	0.34
Challenges	2	4	2	2	0	0	2.40	1.16	0.48
Success	1	4	5	0	0	0	2.40	0.49	0.20

6.5 Assessment of student achievement in CVEEN 3100

Learning outcomes were assessed based on the results of the final assignment students completed for the infrastructure, risk, and resilience unit implemented as a result of the intervention. Ten students were selected at the conclusion of the semester to provide a snapshot-in-time of proficiency levels toward achieving student-learning outcomes. Students receiving the highest two grades for the course were selected for the study; similarly, the two students (completing the course) who received the lowest final course grades were also included in the study. These four students act as bookends of course expectations, achievement, and outcomes. The remaining six students were randomly selected, to provide a full range of course makeup. Table 5 characterizes outcome proficiency levels related to a mid-semester report students submitted to fulfill course requirements on the infrastructure, risk, and resilience unit.

Consider the following two examples of student work to illustrate learning outcomes and provide a rationale for the assessment rubric. In the first example, Student #1 (Needs (An), Challenges (An), Success (Ap)) analyzes challenges associated with blast resistant design standards and specifications required of federal buildings and military installations considering increased material costs, knowledge gaps between military and civilian sectors, and lack of federal assistance. Student #1 concludes with a “three-fold” recommendation “on this complex issue”:

> Terrorist attacks can happen anywhere and to anyone, and civilian structures are by no means safe. First, the standards, specifications, and design software used by the US federal government and military **must be open-source for civilian structural engineers.** Once the information that exists is widely available, **leaders in the Civil Engineering field can analyze further the gaps in our understanding** of blasts and how they affect structures. **This will lead to the changing and improvement** of the current standards, **and perhaps even a lowered cost** as new research is brought to this issue. Finally, a list of sorts must

> be made to prioritize the civilian structures that need to be retrofitted or rebuilt entirely […]. **This process, although long and complicated, is one that must be initiated** to fill this huge gap in our structural design standards, and most importantly, to save lives. (Student #1, emphasis added)

In this example, Student #1 acknowledges the "long and complicated" nature of the problem while arguing that more "open-source" sharing of information among industry leaders "will lead to the changing and improvement of current standards, and perhaps even […] lower cost[s]." The comprehension of the problem in this recommendation, and the systematic way in which the student argues for specific action while not simply calling for more research is quite nuance when compared with peers.

In contrast to Student #1, consider Student #2 (Needs (C), Challenges (Ap), Success (C)) who also wrote about infrastructure as it relates to terrorism, blast resistant structures, and disaster planning. In a report titled *A Look at Reinforcing Critical Structures against Explosive Blasts and Seismic Activity,* Student #2 concludes:

> Further research is needed into these [blast resistant] materials in order to fully determine their applicability in new construction and retrofits of current structures. Fiber reinforced concrete shows much promise in creating stronger concrete that retains its strength post blast. Since it also resists the propagation of cracks, it is a good alternative to standard concrete in any usage. In retrofitting structures where using fiber reinforced concrete is not advantageous or economical, fiber reinforced polymer laminates or an elastomeric polymer are both good options. […] **Retrofitting critical structures with these materials would make them extremely more resilient** to both explosive blasts and seismic activity. **If these materials were to be used in conjunction on new structures, the structures** [sic] **resilience to blasts and seismic events would substantially increase.** These reinforced structures [sic] **possibility of collapse would be miniscule,** and **thereby considerably decreasing** [sic] **the loss of life** in a terrorist attack or seismic event. (Student #2, emphasis added)

Unlike Student #1 whose conclusion acknowledges the complexity of the issue as it relates to multiple factors and stakeholder pressures, Student #2 concludes, that the use of improved construction material such as "fiber reinforced concrete" or "elastomeric polymers" will in essence solve the problem. The problem with this rationale, however, neglects any account of why such materials are not already readily used. Where Student #1 acknowledges that costs will lower and change will occur gradually as the entire knowledge community of civil engineering improves, Student #2, like so many engineering students, tries to engineer a technical solution to a problem without first recognizing the highly-complex nature of the problem and the countless social, political, and economic factors that influence structural design and standards.

7 Summary

The work discussed here presents the early stages of the authors' own development in preparation for a more systematic approach for teaching infrastructure. The principal questions asked by the team include: 1) What does infrastructure education mean and how does it differ from civil engineering education? 2) How do we teach it? And 3) How do we assess student achievement within it?

Question
What is civil infrastructure education and how does it differ from traditional civil engineering education?

Our Answer
The primary difference is the large-scale, holistic perspective that infrastructure education encourages. The educational content now encompasses the inter-relationships between systems and people at a macro-scale level. The design of a bridge, for instance, is not only about the technical aspects of vehicular needs, structural needs, and foundation needs. The civil engineering professional must also maintain an ability to work with a wide range of stakeholders such as city business development representatives, local land owners, regional and local transportation planners, political and environmental representatives, etc. Hence, it is crucial to establish a body of knowledge or competency skills associated with how a civil engineering technical specialist interacts with and contributes to the success of such a project. Our "answer" of what civil engineering infrastructure is is partially provided by the rubric presented herein.

Question
How to teach civil infrastructure?

Our Answer
A variety of exercises from the CIT-E workshop were easily adapted and extended to the specific courses and at a variety of levels (from first to third year; the fourth year was not presented). We found value was gained by integrating these exercises in selected courses and that it was not necessarily the case that a whole-scale change of the program was required.

Question
How do we assess student achievement?

Our Answer
Part of the assessment answer is to require that student work achieve specific aspects related to the components of an infrastructure perspective. In other words, explicitly require that students address issues of hazard, risk, sustainability, socio-economic impact, etc. Of course, that does mean that time and space in the program need to be made in order to provide examples and opportunities for feedback and progress. Here, the CIT-E examples provide an arch-type for the learning activities. Deeper assessment of student achievement (not grades, but review of where the students are at and where we want them to go) is, though, a bit more challenging. Ultimately, much of what is taught involves attitudes and personal values in addition to cognitive abilities,

which points to a need to implement assessment in the affective domain rather than only the cognitive domain.

The significance of the efforts described in this paper attest to the importance of the fact that civil infrastructure systems are built and/or natural facilities or processes that are associated with enabling humans to live, move, work, and play. Because they tend to be large-scale, and of a unique nature, rather than a product of nature, particular elements of a particular system are designed to suit unique locations and/or purpose. As such, civil infrastructure systems can be understood by the processes in which civil engineers design, construct, manage, maintain, operate and protect efficient, resilient and sustainable civil infrastructure systems. Within this practice is a recognition of the role that systems play in societal functioning while accounting for how human behavior and social organizations contribute to and affect the performance of a given system. When students are taught this perspective of infrastructure, they are often more proficient in their efforts to incorporate all of the stakeholders in the development and implementation of the facilities and processes they are asked to study.

For example, if a student were asked to research and write about the impacts of an aging water treatment system, and the effects such a system entails for a community such as Flint, Michigan residents are now experiencing, the student must be able to progress through course materials, independent research, and peer interactions and not simply summarize events, or even point to its root causes. Rather the student must be able to analyze events not as a singular incident, but, rather, evaluate and synthesize the entire infrastructure system in which stakeholder interests and needs; natural, manmade, and political hazards; and social, technical and economic challenges all coalesce over a long period of time to produce, oftentimes disastrous and deadly consequences.

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APPENDIX

Infrastructure Assessment Rubric

	Performance Level					
Category	**Understand**	**Comprehend**	**Apply**	**Analyze**	**Evaluate**	**Synthesize**
Project Needs and Wants of Stakeholders						
Stakeholders - Interests - Needs - Competing Interests	Identifies basic list of stakeholders and needs (two or three of each)	"Shotgun" list of stakeholders without much regard to primary; superficial statement of needs	Focuses on primary stakeholders and primary needs and interests; recognizes secondary	Identifies competing needs and interests	Identifies potential consequences related to serving competing needs and interests	Establishes priorities amongst competing needs and interests
Project Hazards and Challenges						
Hazards - Natural and Manmade - Socio, Economic, and Political - Consequences - Interdependence Engineering Challenges - Technical Models - Technical Form and Function - Construction Means and Methods	States basic list of hazards and/or engineering challenges but has shallow depth	"Shotgun" list of hazards and/or challenges; superficial statement if any recognition of consequences and/or interdependence	Reasonable and comprehensive list of hazards and/or challenges; recognizes potential interdependence	Consequences of hazards and/or engineering challenges identified, i.e., identifies risk; Identifies potential solutions	Differentiates between primary and secondary hazards, challenges, and risks;recognizes interdependence of solutions	Establishes priorities amongst competing hazards, challenges, solutions, and their risks
Project Success						
Project Criteria - Engineering - Safety, Health, Welfare - Sustainability - Resilience - Short- and Long-term Impact	Superficial list of criteria	"Shotgun" list of criteria	Comprehensive list; metric of success recognized but not robust	Metric of success clearly established	Connections between competing areas identified and clarified	Prioritizes criteria using well established principles